PATENT APPLICATION OF

KEVIN I. BERTNESS

ENTITLED

ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE
VEHICLE

Docket No. C382.12-0105

ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE

BACKGROUND OF THE INVENTION

The present invention claims priority to Provisional Application Serial No. 60/132,622, filed May 5, 1999, and entitled AUTOMOTIVE VEHICLE BATTERY CHARGING SYSTEM; U.S. Provisional Application No. 60/165,208, filed November 12, 1999, and entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; and Provisional Application Serial No. 60/175,762, filed January 12, 2000, and entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE, which are incorporated herein by reference in their entirety.

The present invention relates to automotive vehicles. More specifically, the present invention relates to an energy management and monitor system for a battery of an automotive vehicle.

Automotive vehicles powered by combustion engines typically include a battery. The battery is used to power the electrical system when the engine is not running. Additionally, the engine is used to charge the battery. The engine is also used to power electrical components of the vehicle when the engine is running.

Vehicles contain charging systems, simply referred to as an "alternator," which are powered by the engine and used to charge the battery. Typical prior art charging systems have been a simple voltage regulator connected to the output of an alternator. The voltage regulator is used to set a voltage generated by the alternator which is applied to the battery. However, this simple technique does not take into account the actual condition of the battery as the

voltage across the battery is not an accurate representation of the battery's condition. Additionally, such systems do not provide any information about the use of the battery, or the

5   battery's current state of charge or state of health.

SUMMARY OF THE INVENTION

Various aspects of the present invention provide a method and/or an apparatus for monitoring or controlling charging of a battery in a vehicle. In one

10   aspect, a method is provided for charging a battery in a vehicle having an internal combustion engine configured to drive an alternator electrically coupled to the battery and adapted to charge the battery with a charge signal applied to the battery. The method

15   includes coupling to the battery through a four point Kelvin connection, measuring a dynamic parameter of the battery using the Kelvin connection, where the dynamic parameter measurement a function of a time varying signal. A condition of the battery as a function of the

20   measured dynamic parameter. The charge signal from the alternator is controlled in response to the determined condition of the battery.

In another aspect, an apparatus for monitoring the condition of a storage battery while the storage

25   battery is coupled in parallel to an electrical system of an operating vehicle is provided. the apparatus includes a first electrical connection directly coupled to a positive terminal of the battery, a second electrical connection directly coupled to a negative

30   terminal of the battery, and the first and second electrical connections are coupled to a voltage sensor to measure a time varying voltage across the battery. A third electrical connection is directly coupled to the positive terminal of the battery and a fourth electrical

connection directly is coupled to a negative terminal of the battery, the third and fourth electrical connections are coupled to a forcing function having a time varying component. In one aspect, a current sensor is provided

5   which is electrically in series with the battery. A microprocessor is configured to determine the condition of the battery as a function of a dynamic parameter of the battery based upon the measured voltage and the forcing function.

10   BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified block diagram showing a battery monitor in a vehicle in accordance with one embodiment of the present invention.

Figure 2 is a more detailed schematic diagram

15   showing the battery monitor of Figure 1.

Figure 3 is a simplified block diagram showing steps in performing diagnostics in accordance with one aspect of the present invention.

Figure 4 is a simplified block diagram showing

20   steps in collecting data for use with the present invention.

Figure 5 is a simplified block diagram which illustrates performing diagnostics on a starter motor of the vehicle of Figure 1.

25   Figure 6 is a simplified block diagram showing steps related to adjusting the charging profile for charging the battery of the vehicle of Figure 1.

Figure 7 is a graph which illustrates one sample curve of regulator voltage output versus state of

30   charge for the battery of Figure 1.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

The present invention offers an apparatus and method for monitoring the condition of the battery and controlling charging of the battery. Such a method and

apparatus can be part of a general energy management system for a vehicle.

Figure 1 is a simplified block diagram showing an automotive vehicle 10 which includes a battery monitor 12 in accordance with one embodiment of the present invention. Vehicle 10 includes vehicle loads 14 which are shown schematically as an electrical resistance. A battery 18 is coupled to the vehicle load 14 and to an alternator 20. Alternator 20 couples to an engine of the vehicle 10 and is used to charge battery 18 and provide power to loads 14 during operation.

In general, automotive vehicles include electrical systems which can be powered when the engine of the vehicle is operating by a generator, or alternator. However, when the engine is not running, a battery in the vehicle is typically used to power the system. Thus, the standard generator system in a vehicle serves two purposes. The generator is used to supply power to the vehicle loads, such as lights, computers, radios, defrosters and other electrical accessories. Further, the generator is used to recharge the battery such that the battery can be used to start the vehicle and such that the battery may power the electrical accessories when the engine is not running.

A standard generator system typically consists of a three phase AC alternator coupled to the engine by a belt or a shaft, rectification diodes and a voltage regulator. These components may exist separately or be part of an integral unit and are typically, somewhat inaccurately, referred to as an "alternator". The voltage regulator is configured such that a constant voltage is supplied by the charging system, regardless of the current being drawn by the electrical system. The actual load applied to the generator system varies

depending upon the number of accessories that are activated and the current required to recharge the battery. Typical values for the voltage regulator output are between 13.5 and 15.5 volts, depending upon

5 the vehicle manufacturer and particular battery chemistry. Further, the voltage on a specific vehicle can also be compensated for ambient temperature.

This prior art approach has a number of draw backs. The output voltage of the generator must be

10 selected to be high enough to rapidly charge the battery under any condition and regardless of the state of charge of the battery. Electrical loads on the vehicle are designed to operate at 12.6 volts, the voltage provided by the battery when the engine is switched off.

15 However, these electrical loads must also operate at the higher voltage supplied when the generator system is on. This higher voltage which is impressed upon the electrical system causes higher I^2R (resistive) losses in the loads due to the increased voltage level. This

20 wastes energy and causes the components to heat. This results in reduced life of the electrical circuitry, higher operating temperatures and wasted energy which must ultimately come from the primary fuel source used to operate the engine.

25 The high voltage across the battery is necessary when the battery's state of charge is low in order to rapidly recharge the battery. However, when the battery's state of charge is within an acceptable range (which occurs most of the time at normal driving

30 speeds), the high voltage across the battery results in high I^2R (resistive heating) losses within the battery resulting in waste of energy, heating of the battery causing premature battery failure, gassing of the battery also resulting in premature failure and heating

of electrical components causing premature component failure.

One aspect of the present invention includes the recognition of the aforementioned problems associated with prior art battery charging techniques. In one aspect of the present invention, a battery charging system controller is provided which monitors the condition of the battery under charge and controls the charging system in response to the condition of the battery. With such general aspects of the invention, the particular implementation of the battery monitor and charge control can be selected as appropriate.

In the embodiment illustrated in Figure 1, battery monitor 12 includes a microprocessor 22 coupled to a voltage sensor 24, a current sensor 26 and a forcing function 28. Microprocessor 22 may also include one or more inputs and outputs illustrated as I/O 30 adapted to couple to an external databus or to an internal databus associated with the vehicle 10. Further, a user input/output (I/O) 32 is provided for providing interaction with a vehicle operator. In one embodiment, microprocessor 22 is coupled to alternator 20 to provide a control output 23 to alternator 20 in response to inputs, alone or in various functional combinations, from current sensor 26, voltage sensor 24 and forcing function 28. In one embodiment, the control output 23 is configured to control alternator 20 such that a nominal voltage output from alternator 20 is 12.6 volts, typical of the nominal open-circuit voltage of the battery 18. Further, microprocessor 22 can raise the output voltage from alternator 20 in accordance with an inverse relationship to the state of charge of battery 18. This can be configured such that alternator 20 only charges battery 18 when necessary, and only

charges battery 18 as much as is necessary. This charging technique can increase battery life, lower component temperature of loads 14, increase the lifespan of loads 14 and save fuel. This configuration provides a feedback mechanism in which the state of charge of battery 18 is used to control the charging of battery 18. The battery monitor 12 is easily installed in a vehicle electrical system. A single shunt current sensor 26 must be inserted in one of the primary battery cables and a control line provided to allow control of alternator 20. The control can be by simply adjusting the voltage supplied to a voltage regulator of alternator 20 to thereby control charging of battery 18. The battery monitor 12 can be a separate, self-sufficient and self-contained monitor which operates without requiring interaction with other components of the vehicle, except in some embodiment, alternator 20.

Figure 1 also illustrates a Kelvin connection formed by connections 36A and 36B to battery 18. With such a Kelvin connection, two couplings are provided to the positive and negative terminals of battery 18. This allows one of the electrical connections on each side of the battery to carry large amounts of current while the other pair of connections can be used to obtain accurate voltage readings. Because substantially no current is flowing through the voltage sensor 24, there will be little voltage drop through the electrical connection between sensor 24 and battery 18 thereby providing more accurate voltage measurements. In various embodiments, the forcing function 28 can be located physically proximate battery 18 or be connected directly to battery 18. In other embodiments, the forcing function 28 is located anywhere within the electrical system of vehicle 10. In one aspect, the present invention includes an

in-vehicle battery monitor 12 which couples to battery
18 through a Kelvin connection and further may
optionally include a current sensor 26 and may be
capable of monitoring battery condition while the engine
5   of vehicle 12 is operated, loads 14 are turned on and/or
alternator 20 is providing a charge signal output to
charge battery 18.   In one particular embodiment, the
combination of the Kelvin connection formed by
connections 36A and 36B along with a separate current
10   sensor 26 connected in series with the electrical system
of the vehicle 10 is provided and allows monitoring of
the condition of battery 18 during operation of vehicle
10.   The use of an current sensor 26 is used to provide
a monitor of the total current I_T flowing through
15   battery 18.

In operation, microprocessor 22 is capable of
measuring a dynamic parameter of battery 18.   As used
herein, a dynamic parameter includes any parameter of
battery 18 which is measured as a function of a signal
20   having an AC or transient component.   Examples of
dynamic   parameters   include   dynamic   resistance,
conductance,   admittance,   impedance   or   their
combinations.   In various aspects of the invention, this
measurement   can   be   correlated,   either   alone   or   in
25   combination with other measurements or inputs received
by microprocessor 22, to the condition or status of
battery 18.   This correlation can be through testing of
various batteries and may be through the use of a lookup
table   or   a   functional   relationship   such   as   a
30   characterization curve.   The relationship can also be
adjusted based upon battery construction, type, size or
other parameters of battery 18.   Examples of various
testing techniques are described in the following
references which are incorporated herein by reference

U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE;

5   U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING; U.S. Patent No.

10   4,881,038, issued November 14, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING TO DETERMINE DYNAMIC CONDUCTANCE; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin, entitled ELECTRONIC BATTERY TESTING

15   DEVICE WITH STATE-OF-CHARGE COMPENSATION; U.S. Patent No. 5,140,269, issued August 18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR ASSESSING BATTERY/CELL CAPACITY; U.S. Patent No. 5,343,380, issued August 30, 1994, entitled METHOD AND APPARATUS FOR SUPPRESSING TIME

20   VARYING SIGNALS IN BATTERIES UNDERGOING CHARGING OR DISCHARGING; U.S. Patent No. 5,572,136, issued November 5, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,574,355, issued November 12, 1996, entitled

25   METHOD AND APPARATUS FOR DETECTION AND CONTROL OF THERMAL RUNAWAY IN A BATTERY UNDER CHARGE; U.S. Patent No. 5,585,728, issued December 17, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,592,093,

30   issued January 7, 1997, entitled ELECTRONIC BATTERY TESTING DEVICE LOOSE TERMINAL CONNECTION DETECTION VIA A COMPARISON CIRCUIT; U.S. Patent No. 5,598,098, issued January 28, 1997, entitled ELECTRONIC BATTERY TESTER WITH VERY HIGH NOISE IMMUNITY; U.S. Patent No.

5,757,192, issued May 26, 1998, entitled METHOD AND
APPARATUS FOR DETECTING A BAD CELL IN A STORAGE BATTERY;
U.S. Patent No. 5,821,756, issued October 13, 1998,
entitled ELECTRONIC BATTERY TESTER WITH TAILORED
COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No.
5,831,435, issued November 3, 1998, entitled BATTERY
TESTER FOR JIS STANDARD; U.S. Patent No. 5,914,605,
issued June 22, 1999, entitled ELECTRONIC BATTERY
TESTER; U.S. Patent No. 5,945,829, issued August 31,
1999, entitled MIDPOINT BATTERY MONITORING; U.S. Patent
No. 6,002,238, issued December 14, 1999, entitled METHOD
AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS
AND BATTERIES; U.S. Patent No. 6,037,777, issued March
14, 2000, entitled METHOD AND APPARATUS FOR DETERMINING
BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE;
and U.S. Patent No. 6,051,976, issued April 18, 2000,
entitled METHOD AND APPARATUS FOR AUDITING A BATTERY
TEST.

In the specific embodiment illustrated in
Figure 1, the forcing function is a function which
applies a signal having an AC or transient component to
battery 18. The forcing function can be through the
application of a load which provides a desired forcing
function in which current is drawn from battery 18, or
can be through active circuitry in which a current is
injected into battery 18. This results in a current
labeled I_F in Figure 1. The total current, I_T through
battery 18 is due to both the forcing function current
I_F and the current flowing through loads 14, I_L.
Current sensor 26 is positioned to sense the total
current I_L. One example battery dynamic parameter, the
dynamic conductance (or reciprocally the battery
resistance) can be calculated as:

$$\Delta G = V = \Delta I_T / \Delta V \qquad \text{EQ. 1}$$

where ΔV is the change in voltage measured across the battery 18 by voltage sensor 24 and ΔI_T is the change in total current measured flowing through battery 18 using

5   current sensor 26. Note that Equation 1 uses current and voltage differences. In one embodiment, the change in voltage and change in current are measured over a period of 12.5 seconds and at a rate of 50 msec to thereby provide a total of 20 readings for ΔV and ΔI_T

10   every second. The forcing function 28 is provided in order to ensure that the current through battery 18 changes with time. However, in one embodiment, changes in I_L due to loads 14 or the output from alternator 20 can be used alone such that $\Delta I_T = \Delta I_L$ and the forcing

15   function 28 is not required.

In one embodiment, the voltage and current sensors provide synchronized operation, within one microsecond, and are substantially immune to measurement errors due to network propagation delays or signal line

20   inductance. Furthermore, microprocessor 22 can detect a failure of the voltage regulator and alternator 20 if the voltage output exceeds or drops below predetermined threshold levels. This information can be provided to an operator through user interface 32, for example, a

25   "service regulator soon" indication.

A temperature sensor 37 is provided which can be coupled directly to one of the terminals of the battery 18 for measuring battery temperature. The temperature sensor 37 can be used in determining the

30   condition of the battery, as battery condition is a function of temperature and can be used in estimating the amount of power which will be required to start the

engine of the vehicle. Any type of temperature sensor can be used, for example, a thermistor, thermocouple, RTD, semiconductor or other temperature sensor.

In one embodiment, current sensor 26 comprises a resistance shunt of 250 μohms and current through the shunt is determined by measuring the voltage drop across the shunt. However, other types of current measurement techniques can also be used such as Hall Effect sensors or through an inductance probe. The change of voltage across the battery and the resultant change in current through the battery is sampled using, for example, one or more analog to digital converters. This information can be correlated to determine the total capacity, such as the total Cold Cranking Amp (CCA) capacity of the battery.

Note that during the measurement cycle, vehicle loads 14 may be applied unexpectedly causing noise to be present in the measurements. One technique which might be considered to reduce the noise is to discard those samples which are outside of a predetermined or adjustable window or are outside of the dynamic range of the analog to digital converter. However, quite unexpectedly it has been found that the accuracy of measurements can be increased by increasing the dynamic range of the analog to digital converters, at the expense of the accuracy of the samples obtained from the converter. By averaging all of the samples, even those which are statistically large or small relative to other samples, the present invention is capable of providing accurate voltage and current measurements even in a noisy environment. By averaging samples, and providing sufficient dynamic range for the analog to digital converter, no samples will be

discarded and errors in the measurements will tend to cancel against other errors.

In general, the present invention uses the direct relationship between the dynamic conductance of the battery and the condition of the battery. For example, if a battery drops more than 15% below its rated capacity, microprocessor 22 can provide an output which indicates that the battery 18 should be replaced. Further, the conductance can be used to determine the charge level of the battery. Such a measurement can be augmented to improve accuracy by monitoring the total current flowing into battery 18, or out of battery 18, using current sensor 26. The voltage across the battery 18 can also be used to determine the charge used in the determination of charge level. In general, the state of charge can be determined as a function of various combinations either alone or together of battery state of health, temperature, charge balance (charge going into and out of the battery), charging efficiency and initial conditions such as the battery construction, manufacture, plate configuration or other conditions of the battery. The functional relationship can be determined by characterizing multiple batteries or through the use of artificial intelligence techniques such as neural networks.

Figure 2 is a more detailed schematic diagram of battery monitor 12. Figure 2 shows microprocessor 22 which includes a memory 40. Figure 2 illustrates I/O 32 with which can be, for specific examples, a communication link in accordance with various standards such as J1850, J1708, J1939, etc. Memory 40 is shown as an internal memory. However, external memory or an optional external memory 42 can also be provided. In general, memory is provided for storing programming

functions, ratings, variables, etc. Microprocessor 22 can be a microcontroller or any type of digital circuitry and is not limited specifically to a microprocessor. Figure 2 illustrates forcing function

5 28 in greater detail and includes a resistance R_1 44 and a switch S_1 46 controlled by microprocessor 22. Switch 46 can be, for example, a field effect transistor. Voltage sensor 24 is shown as including a differential amplifier 47 coupled to battery 18 through a DC blocking

10 capacitor C_1 48. Shunt 26 is illustrated as a resistance R_2 50 and a differential amplifier 52. Switches S_2 54 and S_3 56 are positioned to selectively couple amplifiers 52 and 47, respectively, to microprocessor 22 and are actuated by a sample control

15 line to provide data samples to microprocessor 22. An analog to digital converter can be an integral part of microprocessor 22 or it can be a separate component to digitize the outputs from amplifiers 47 and 52. Capacitors C_2 and C_3 provide sample and hold circuits.

20 Forcing function 28 can be formed by resistance as illustrated in Figure 2, or by a current sink or through an existing load of the vehicle. Switch S_1 46 can be an FET, or biopolar transistor or can be a mechanical or existing switch in the automotive vehicle.

25 Although shunt 26 is illustrated with a shunt resistance, other types of current sensors such as Hall effect sensors or cable resistance based sensors can be used. Other types of DC blocking techniques can be used to replace capacitancy C_1 48 such as a DC coupled

30 amplifier.

Figure 3 is a simplified block diagram 100 showing diagnostic steps performed by microprocessor 28 in accordance with the invention. At blocks 102 and 104, the dynamic parameter(s) for the battery 18 are

obtained and at block 104 data is collected. The type of data collected at block 104 can be any type of data used in determining the condition of the battery. For example, the data can be values used for ΔV and ΔI_T,

5   information related to the type of battery, etc. This information can be stored in memory 40 for subsequent retrieval by microprocessor 22. The data can be collected over any time period and during any type of engine or battery operation. At block 106,

10   microprocessor 22 performs diagnostics based upon the data stored in memory 40. If a battery fault or impending fault is detected, an output can be provided at block 108 such as providing a "service battery soon" indication on the dash of the vehicle 10.

15   Various aspects of the invention include the particular diagnostics performed by diagnostic block 106. The diagnostics can be simple diagnostics such as a simple if-then rule in which the collected data is compared to various thresholds to provide the diagnostic

20   output. Absolute values of the data can be used for this comparison or various statistical operations can be performed on the data for use in the comparison. For example, averages or standard deviation of the data can be compared to a threshold. The threshold levels can be

25   determined through testing of the vehicle and entered into memory 40 during manufacture. Preferably, when battery 18 is replaced, the thresholds are updated accordingly.

         In more advanced embodiments of the diagnostic

30   block 106, microprocessor 22 can perform diagnostics using fuzzy logic, neural networks or artificial intelligence techniques. Neural networks can advantageously be used as they do not require that the battery, alternator and vehicle loads be modeled.

Instead, neural networks are capable of learning what "normal" data collected at step 104 should be, and can provide an indication when a pattern of the data is drifting outside of normal operation. Further, the

5   neural network can be "trained" to recognize potential sources of the failure and provide an expected time until the system completely fails. These diagnostic techniques can be selected and implemented such that the operator is warned of an impending failure, prior to the

10   complete failure of the battery 18 or alternator 20.

           Figure 4 is a block diagram 130 showing example steps in accordance with data collection and calculation of a dynamic parameter in accordance with the present invention. Of course, as should be pointed

15   out with respect to all of the flow charts set forth herein, those skilled in the art will recognize that the particular functions of the blocks and the order in which the blocks are executed can be easily rearranged and the invention is not limited to the specific

20   embodiments set forth herein.

           In block diagram 130, at block 132 microprocessor 22 obtains an initial voltage V_1 across battery 18 using voltage sensor 24 and an initial current I_{T1} through battery 18 using current sensor 26.

25   Next, the forcing function 28 is applied to battery 18 at step 133. At block 134, microprocessor 22 obtains values V_2 and I_{T2} with the forcing function applied, and at step 136 the forcing function is removed. Values for ΔV and ΔI_T are calculated at step 138. In one example

30   embodiment, the forcing function is applied for a duration of 100 μSec 20 times every second. N values are obtained at block 140. In one example, N is equal to 256. At block 142, the average of ΔV and I_{T2} for the N samples is calculated and a dynamic parameter for the

batter 18 is determined at block 144. This dynamic
parameter can be correlated to a condition of the
battery at block 146 and displayed on user I/O 32,
output through I/O 30 or used to control alternator 20
through alternator control 23.

In one aspect of the invention, the battery
monitor performs a state of charge measurement, in real
time and regardless of battery polarization, and
automatically corrects for the state of health of the
battery and the battery temperature. In general, state
of health can be determined as a function of the battery
conductance and the open circuit voltage across battery
18. For example, the state of health can be determined
as:

EQ. 2

where k_1 and k_2 are constants which are related to the
type of battery, G is the measured conductance of the
battery, rating is a rating for the battery and $f(V_{oc})$
is a relationship between the state of charge and the
open circuit voltage of the battery as set forth in the
aforementioned Champlin and Midtronics, Inc. patents.
The state of health will range between 0 and 100%.
Using the state of health determined by Equation 2, the
state of charge (from 0 to 100%) can be determined in
accordance with Equation 3:

$$SOCt_2 = 100 * \frac{\left[\int_{t_1}^{t_2} i\, dt \int_{t_1}^{t_2} e(T)\, dt \int_{t_1}^{t_2} e(i)\, dt\right]}{(SOH)\,(AMP\text{-}HOURCAPACITY)} + SOC_{t_1} \qquad \text{EQ. 3}$$

where t_1 is the time at which the state of charge is
known (i.e., from the period of overcharge, for
example), t_2 is the present time, i is the current

(amps) in or out of the battery at time t, T is the battery temperature, e(T) is the charge acceptance efficiency at temperature T, and e(i) is the charge acceptance efficiency at current i. Of course,

5   Equations 2 and 3 are simply examples of state of health and state of charge measurements and other techniques can be used in accordance with the invention.

Using the battery state of charge and the battery state of health, battery monitor 12 can predict

10   the starting capabilities of a starter motor of vehicle 10. For example, by comparing the amount of current measured by current sensor 26 which has been previously been required to start the engine of vehicle 10 for a particular temperature, microprocessor 22 can determine

15   if the current state of charge of the battery for the current state of health at the current temperature will be sufficient to provide enough current to start the engine. The performance and any degradation in the starter motor can also be taken into account by

20   microprocessor 22. For example, if the amount of current required to start the engine has been increasing with time, microprocessor 22 can extrapolate and predict what amount of current will be required to start the engine in the future. Figure 5 is a simplified block

25   diagram 200 which illustrates steps performed by a microprocessor 22 in diagnosing the starting capability of battery 18. At block 202, microprocessor 22 determines the starting capability of battery 18. For example, the starting capability can be an estimation or

30   measurement of the amount of current which battery 18 can supply over a short duration. At block 204, microprocessor 22 estimates the starting requirements of the starting motor of the engine of vehicle 10. For example, the past requirements of the starter motor can

be recalled from memory 40 and any trend can be used to predict what will be required for starting the engine. Other inputs can also be used in this determination such as the current temperature. At block 206, a starter diagnostic output is provided. For example, if it appears that the battery will have difficulty in operating the starter motor for a sufficient duration to start the motor of the vehicle, vehicle loads 14 can be selectively switched off by microprocessor 22 through I/O 30. Additionally, a warning can be provided to an operator through user I/O 32 of an impending problem, prior to its actual occurrence, such that the battery 18 can be replaced.

In another aspect of the invention, microprocessor 22 can be adapt or alter the performance of the engine and/or loads 14 based upon a number of different parameters in order to provide optimal charging to battery 18. For example, microprocessor 22 can interface to a data bus of a microprocessor of the vehicle 10 through I/O 30 to control engine operation. Alternatively, microprocessor 22 can be the same microprocessor used to control vehicle operation. The microprocessor 22 can adjust the idle speed of the engine, shift points of the transmission and the load placed on the electrical system by some of the loads 14 to increase or decrease the rate of battery charging based upon the expected driving patterns of an operator. For example, if the microprocessor has observed that the vehicle is normally operated for a short duration, the microprocessor 22 can increase the idle speed of the engine and attempt to reduce loads placed on battery 18 to increase the charging rate of battery 18. Further, microprocessor 22 can alter the shift points of the transmission to cause the engine to operate at a high

(or lower) speed than normal. The prediction of engine operation can also be based upon time of day and the day of the week such that repeated driving patterns can be accounted for, for example, commuting to work. Further, in vehicles where it is possible to recognize the operator of the vehicle, such as through the seat position memory in a power seat of the vehicle, microprocessor 22 can alter the charging pattern based upon the driving characteristics of a specific driver.

Figure 6 is a simplified block diagram flowchart 250 showing steps performed by microprocessor 22 in adjusting engine speed or loads to control the charge in battery 18. Block 252, microprocessor 22 determines the charge required by battery 18 to become fully charged, this determination can be based upon a measurement of the current charge level of battery and a determination of the maximum amount of charge that battery 18 can hold, for example, as a function of the state of health of battery 18. At block 254, microprocessor 22 predicts the expected driving pattern for the upcoming engine use. At block 256, microprocessor 22 adjusts the engine operation and/or vehicle loads 14 in order to optimize the charging of the battery 18 based upon the charge required as determined at step 252 and the driving pattern predicted at step 254. During engine operation, microprocessor 22 continues to monitor the battery state of charge at block 258 and adjusts the charging accordingly at block 260. Once battery 18 has been fully charged, the microprocessor 22 can reduce the charging rate as appropriate.

If the drive cycle is, or has tendency to be, insufficient to charge the battery 18, microprocessor 22 can provide an output to an operator through user I/O 32

to indicate that either the vehicle must be driven for an extended period of time or an alternative charging method be used to charge battery 18. An indication can also be provided as to a prediction regarding how many

5   further such drive cycles can be supported by the battery 18 before it will have insufficient remaining charge to start the vehicle.

As discussed above, in one aspect of the present invention, the output from the alternator 20 is

10   adjusted based upon the state of charge and/or the state of health determination(s). Figure 7 is a graph showing the regulator voltage output from alternator 20 as a function of the state of charge of battery 18. As illustrated in Figure 7, microprocessor 22 reduces the

15   voltage output from alternator 20 as the state of charge of battery 18 increases to 100% charge. The particular profile can be adjusted to a specific battery, alternator and/or engine configuration or to the driving characteristics of an operator. Such a system can

20   significantly reduce or eliminate overcharging of battery 10 and the generation of excessive heat. Further, such a technique can be used to reduce or eliminate the undercharging of battery 10. Additionally, by adjusting the voltage based upon the

25   state of charge, battery 18 and system component life will increase. For example, vehicle loads 14 will be exposed to over voltages for a reduced amount of time. This also allows the various systems components to be optimized for particular charging requirements or

30   voltage levels. In general, the output of the alternator 20 can be reduced and the battery capacity required for a particular vehicle can be reduced because battery charge will be more efficiently maintained. This can reduce overall vehicle weight and improve

vehicle mileage. Further still, IR (current-resistance) type losses in the electrical system and overcharging will·be reduced thereby reducing the load on the vehicle engine and improving efficiency of the vehicle. In

5 general, this technique will improve vehicle reliability by reducing heat due to excessive IR losses, increasing battery life, providing early detection of impending battery failure and insuring proper vehicle operation even with after market batteries which are used to

10 replace the original battery.

If such a system is implemented when the vehicle is originally manufactured, monitor 12 allows battery management over the entire life of the vehicle. This can be both during assembly and delivery of the

15 vehicle as well as during the lifespan of actual vehicle operation. Additionally, one aspect includes a storage battery 18 with rating information carried in a computer storage device such as a digital memory within a housing of the battery. This data can be communicated to

20 monitor 12 through I/O 30. In one aspect, the electrical connections to the battery are also used as a data communication bus such that monitor 12 can communicate with the storage device in battery 18. The storage device can also be used to store the history,

25 such as the charging and usage history, of battery 18.

Battery monitor 12 can monitor and diagnose operation of alternator 20. For example, a typical alternator provides a multiphase output. By monitoring the data points collected and stored in memory 40,

30 microprocessor 22 can observe the loss of one or more phases in the alternator's output. Similarly, the failure of a rectifying diode in alternator 20 can be detected by microprocessor 22 by observing an asymmetrical ripple pattern. Microprocessor 22 can

provide an output to an operator through user I/O 32 such as a "service alternator soon" output. This information can also be communicated to the vehicle microprocessor through I/O 30.

5   I/O 30 is shown in schematic form and can be any type of input or output and represents, in some embodiments, multiple input(s) and output(s). Various examples of inputs and outputs include a connection to a databus of the vehicle, a connection to a databus

10   adapted to couple to a diagnostic device such as that provided in service equipment, a connection to a remote vehicle monitoring system, such as one that is capable of coupling through a cellular phone connection of the vehicle. In such an embodiment, the vehicle is capable

15   of recording and reporting information to a remote service such as an emergency assistance service or a service provided to monitor the operation of the vehicle and suggest that maintenance be provided. Various types of inputs and outputs can be provided through direct

20   connections or through non-physical connections such as radio frequency or infrared communication techniques. The particular form of the data and standard used for the inputs and outputs can be selected as proprietary or industry standards. Microprocessor 22 can also be

25   capable of providing advanced reporting and control functions through the use of standardized interfaces such as are available through HTML, XML, or various known or proposed alternatives. In such an embodiment, information collected by microprocessor 22 can be viewed

30   through a "web page" interface provided by a browser. Such an embodiment is advantageous because it can provide a user input/output such as user I/O 32 in a standardized form such that it can be viewed or controlled through many types of standardized devices.

In such an embodiment, information can be reported to, or the monitor 12 can be controlled, from a remote location. Additionally, if the vehicle 10 includes a browser type interface which may become commonly available in vehicles, the microprocessor 22 can be controlled and communicate through the vehicle's browser. In one aspect, vehicle monitor includes an IP (Internet Protocol) address such that it is capable of communicating in accordance with the Internet Protocol. When coupled to, for example, a cellular telephone connection of the vehicle, the battery monitor 12 is capable of being monitored and controlled from a remote location coupled through the Internet. However, as mentioned above, such an interface also provides a simple technique for interfacing the monitor 12 with a local computer in the vehicle and displaying information from the monitor 12 for use or control by an operator.

Through the use of the data collected by microprocessor 22 and memory 40, microprocessor 22 is also capable of detecting the imminent failure of the starter motor of the vehicle. For example, by monitoring the voltage drop through the system during starting, microprocessor 22 can determine the average time to start the engine and the average and peak currents required during starting. Changes in these, or other, measurement values can indicate a degrading starter motor. Upon detection of an impending failure, a "service starter motor soon" indication can be provided to an operator through user interface 32.

Microprocessor 22 can provide an indication that the battery 18 has insufficient capacity or substandard performance and alert an operator accordingly. For example, upon power up, such as that which occurs when battery 18 is replaced, microprocessor

22 can measure the capacity of the battery 18 and provide an indication to the operator if the capacity is less than a threshold level determined by the vehicle manufacturer and stored in the memory of the vehicle

5   computer system.

Microprocessor 22 can generate an audit code (or a warranty code) in response to the various tests and data collected. Such codes are described in U.S. Patent No. 6,051,976, issued April 18, 2000, entitled

10   METHOD AND APPARATUS FOR AUDITING A BATTERY TEST which is assigned to the present assignee and is incorporated herein by reference. In such an embodiment, microprocessor 22 encodes data collected or obtained during its operation. For example, raw data related to

15   a battery test can be obtained and/or the ultimate result of the battery test and subsequently encoded by microprocessor 22. The encoding can be a simple transposition cipher in which the locations and values of various bytes of information are rearranged. Such a

20   code can be designed to prevent falsification of data which can occur where unscrupulous individuals are attempting to submit a falsified warranty claim for a failed component to a manufacturer. This coding technique allows the manufacturer to verify information

25   when a warranty is submitted. Additionally, the information can be used to track operator error and assist in identification and isolation of component failure in order to redesign the components and reduce such failures.

30   In another aspect, microprocessor 22 is capable of automatically calibrating the measurements obtained from voltage sensor 24 and current sensor 26. Using this aspect of the invention, microprocessor 22 can perform automatic or periodic calibrations to

maintain accuracy over the lifespan of the vehicle. Automatic calibration can be provided by selectively switching in calibrated elements having known temperature and time drift characteristics, and using the measured data to correct for instrumentation gains and offsets. For example, a known resistance or voltage source can be selectively coupled to amplifiers 47 or 52. Any offset values from these known values can be stored in memory 40 and used by microprocessor 22 to compensate for errors in measurements.

With the present invention, any polarization of the battery 18 such as that which can result from charging or starting operations, does not produce errors in the measurements performed by microprocessor 22. Specifically, any such errors are eliminated by use of a real-time state of charge algorithm that is independent of the real time battery terminal voltage.

When the engine of vehicle 10 is not operating, microprocessor 22 can enter a sleep mode to reduce current draw and the resultant discharge of battery 18. If desired, microprocessor 22 can periodically "wake up" to perform tests or monitor some aspect of the electrical system of vehicle 10.

A loose or corroded connection to battery 18 can be detected by microprocessor 22 by observing a sudden increase in the resistance across battery 18. An error can be provided to an operator through user interface 32 to alert the operator of the degraded connection.

Microprocessor 22 can also perform diagnostics on the electrical system of vehicle 12 when the engine is not operating. For example, microprocessor 22 can monitor the current being drawn by loads 14 when the engine is not running using current sensor 26. For

example, microprocessor 22 can compare the rate of current draw, over a selectable sample period with a threshold stored in memory 40. If the measured rate exceeds the threshold, there may be a fault in the electrical system of the vehicle. Similarly, a small but constant current drain can also indicate a fault which could lead to the discharge of battery 18. Microprocessor 22 can provide an indication to the user through user interface 32 that excessive current draw has occurred while the engine is off. Such current draw can lead to rapid discharge of battery 18 and prevent starting.

Current sensor 26 can also be used by microprocessor 22 to monitor the current flowing into and out of battery 18. The summation of this current, taken over a time period (i.e., integration) can provide an indication that the battery is not receiving sufficient charge, or can provide an indication of the total charge received by battery 18. This information can be displayed to an operator through user I/O 32. Additionally, the information can be provided on I/O 30. If the information indicates that the battery 18 is not receiving sufficient charge, steps can be taken as discussed above, to increase the charging rate of battery 18.

In one embodiment, microprocessor 22 stores information in memory 40 related to the model number, and/or serial number, capacity or other information related to battery 18. In such an embodiment, battery monitor 12 can be a physical part of battery 18 such that battery specific information can be programmed into memory during manufacture. The battery monitor 12 can provide an output to an operator through a display or other type of output device which is physically located

on the battery 18. Additionally, the display or user I/O 32 can be located within the vehicle. Input/output 30 can be configured to couple to the databus of the vehicle. For example, the battery 18 can include a data

5 plug adapted to plug into the databus of the vehicle such that monitor 12 can exchange information through the databus. Microprocessor 22 can then report this information to the databus of the vehicle using input/output 30. This allows the microprocessor of the

10 vehicle the ability to perform advanced diagnostics and monitoring as the specific battery type is known.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes

15 may be made in form and detail without departing from the spirit and scope of the invention. For example, the circuitry and circuit configuration is provided as simply one embodiment and those skilled in the art will recognize that other configurations can be provided.

20 The particular connections to the battery can be through Kelvin connections which include a "split" Kelvin connection in which the forcing function connection(s) are/is spaced apart from the battery such as that described and illustrated in U.S. patent application

25 Serial No. 09/431,697, filed November 1, 1999 and entitled ELECTRICAL CONNECTION FOR ELECTRONIC BATTERY TESTER which is incorporated herein by reference in its entirety. In a further example of the present invention, alternator 20 can comprise an electronic

30 battery charger such as those used to charge automotive vehicles when the vehicle is stationary or to charge stand by batteries such as those used in remote systems such as cellular sites. In such an embodiment, control line 23 is used to adjust the charger of battery 18

using the techniques set forth herein. In such an embodiment, element 10 shown in Figure 1 illustrates a standby power supply for equipment.